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ECONOMIC PERFORMANCE: EVALUATIONS FOR SOLAR ENERGY*

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ABSTRACT

Economics will likely play a major role in the future adoption of alternative energy technologies. Proper employment of economic t-ols should provide much useful information on impending research, marketing, and policy decisions. One such economic tool, the LASL/UNM economic performance methodology--computer code, is reported on here. A brief history of past solar assessment activities preceeds description of the LASL/UNM code. The inputs, sets of evaluative procedures, and outputs associated with the methodology/code are discussed in detail. Present status plus on-going modifications to the various components are highlighted throughout the discussion. The utility of the LASL/UNM code is demonstrated through illustrative examples of recently completed studies.

INTRODUCTION**

Over the past three years, members of The University of New Mexico (UNM) Resource Economics Group and staff from the Los Alamos Scientific Laboratory (LASL) Energy Systems and Economic Analysis Group have developed an economic performance code to evaluate the potential feasibility of residential solar space and water heating systems. The model--LASL/UNM economic performance code--incorporates two levels of detail: a "micro" approach used for very specific design performance and cost sensitivity studies, and a "macro" approach used to examine the nationwide potential of constrained solar designs.

In the section below we present briefly the past history of our evolving efforts in the assessment of solar residential heating. The two basic approaches--micro and macro--are reviewed next with major components in the LASL/UNM economic performance code outlined. These components are then individually discussed in detail. Illustrative examples of past efforts are highlighted through-out the discussion. Finally, future plans are addressed.

HISTORICAL DEVELOPMENT

In 1975, the National Science Foundation awarded a two year grant

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**A similiar version of this summary discussion appears in Solar Engineering (Noll, 1979a).

to the UNM Resource Economics Program to conduct an economic and environmental assessment of solar and geothermal energy alternatives. The solar portion of the analysis centered upon active solar space and water heating systems with performance data supplied by the Solar Energy Group (Balcomb and McFarland, 1976) of LASL. Results have been reported in an NSF-RANN completion report (Schulze, et al., 1976), and in a document prepared for the Joint Economic Committee of Congress (Schulze, et al., 1977). Subsequent improvements in the data base and economic methodology were made to evaluate the impacts of the original National Energy Plan (April 1977) on solar economics, a report (Roach, et al., 1977) which was relaeased by LASL at the close of 1977. Since that time, passive concepts have been added to the analysis. Preliminary results for the thermal mass storage wall concept appear in the August 1978 AS/ISES Conference Proceedings (Roach, Noll, and Ben-David, 1978) with further analysis forthcoming in Energy: The International Journal, (Roach, Noll, and Ben-David, 1979; Noll and Wray, 1979).

SOLAR ASSESSMENT APPROACHES

Five basic steps are employed in the macro (nationwide) evaluation of solar economic performance. [These same steps are also employed with some modifications in the micro (specific locale) evaluation of design, performance, cost, and comfort tradeoffs for any given solar configuration. More detail on the micro approach is contained in the following paragraph.] These are (1)the specifications of architectural design parameters and active/passive revisions to a conventional tract home--tract home concepts are used for they represent the largest possible market for solar inclusion and greatly facilitate regional comparisons, (2)the specification of the annual thermal performance of the passive designs--simplified methods developed by the Solar Energy Group at LASL are currently being used, (3)the estimation of solar add-on costs which are coupled with performance estimates to calculate costs of alternatively sized solar heating designs, (4)the specification of conventional energy prices and futures by locale, and (5)the determination/evaluation of the economic competitiveness of the various designs based upon life cycle cost and cash flow analysis. It is specifically the LASL/UNM economic performance code (macro portion) that combines all of the information delineated above such that the actual solar evaluation can be made.

The micro approach, rather than taking most design information as given (macro approach), focuses upon design-performance tradeoffs with explicit consideration of cost and comfort factors such that one may optimally size a solar design subject to alternative constraints and criteria. [To date only passive solar designs have been examined through the micro approach, whereas both active and passive configurations have been worked through the macro approach.] Results from hour-by-hour thermal network models are used to determine composite performance equations which express the annual delivered solar heating fraction as a function of the specified input parameters. To ensure compatibility, the input specifications are consistent with architectural design schematics and incremental cost factors attributable to the solar portion of a new single family tract home residence. Performance and incremental solar costs are then combined to arrive at optimal expansion paths which indicate the least cost method or design of providing a given solar fraction. When constraints imposed by material availability, building code requirements, or comfort preferences are considered, the expansion paths are altered so that sizing and design becomes a constrained optimization procedure. Economic performance is then measured by several financial indicators including years to mortgage payback, years to positive savings, net present value, and equivalent annual costs.

A schematic overview presented in Figure 1 portrays the major components and their interrelationships in the LASL/UNM model. Briefly, the components of the LASL/UNM model can be divided into three major categories: inputs, methodology, and output. We discuss each of these components in the sections below. [Passive solar heating concepts shall serve as the vehicle for model presentation.]

INPUTS

The major sets of inputs to the LASL/UNM model include, (1)architectural design specifications with (2)solar add-on cost estimates by location, (3)performance analysis for those architectural design specifications, (4)conventional energy price data with projected futures, and (5)select financial parameters. The LASL/UNM model accepts any user-defined parameter values, although at present we assign specific input values.

The Burns/Peters Architectural Group of Albuquerque, New Mexico have provided architectural schematics, renderings, and solar add-on cost estimates for four passive designs (thermal storage wall, thermal storage roof, direct gain, and attached sunspace) integrated into conventional single family detached tract home residences (Western Research Inc., 1978). Flexibility in design is maintained by costing a wide variety of sizing and option design parameters in each passive configuration so that detailed microeconomic analysis can be conducted (Noll and Wray, 1979). These parameters include number and type of glazings, storage type and volume, night insulation options, glazing area, glazing to storage ratios, interior temperature swings, and selective coatings.

To date, these solar designs have shown a Southwestern flavor with a tract home in Albuquerque, New Mexico serving as a standard. Figure 2 portrays an architectural rendering of a direct gain passive solar configuration. From this rendering with associated detailed schematics of the home and its floor plan solar add-on costs have been estimated. Regional designs and solar add-on costs estimates are presently being developed by several contractors across the U. S. When complete, they should give one a better starting point from which more realistic regional comparative (economic) analyses can be undertaken.

Simplified correlations relating passive solar performance to sizing, design, and climatic parameters have been generated (Balcomb and McFarland, 1978, by the LASL Solar Energy Group using the results from hour-by-hour validated thermal network models such as PASOLE (Balcomb, Hedstrom, and McFarland, 1977) and SUNSPOT (Wray and Balcomb, 1978). The solar load ratio (SLR) methodology provides performance data for the macro study, whereas the detailed computations underlying the SRL calculations are transformed (estimated) by logarithmic Taylor series expansion equations for use in the detailed microanalysis. Additional thermal network modeling for the passive designs is based upon hour-by-hour passive simulation models provided by Bickle/CM, Inc., (Dexter and Reams, 1979).

Solar performance calculations are key to the economic analysis. Without information on solar displacement of conventional fuels, it would be impossible to evaluate the economic performance, and hence its desirability, of any solar design under any given criteria. We are fortunate in having available to us some of the best information to date on solar performance. That information is presently being updated to reflect a modified definition of solar fraction, where only the actual displacement of auxiliary (alternative or backup heating system) fuel is measured as a positive contribution of solar. This definition is more in line with our use of the solar fraction term and its subsequent integration into life cycle cost evaluations. In addition, solar performance for over 200 cities (initially only 80) is now being estimated so that our resolution for the continental U. S. will be greatly expanded. These cities have been chosen because of the availability of average weather data (NOAA supplied weather information under a DOE sponsored contract).

The energy price data base includes current (1977) costs for electricity (kwh), natural gas (mcf), and heating oil (gal). These prices are derived from the published literature where available sublimated by information directed from the utilities if required. In addition, these prices are being updated to 1978/1979. The original collection of prices only covered one site per state in the continental

U. S., but is now being expanded to include over 200 cities (the same set of cities as solar performance data is being estimated). Various energy price futures have been inputed to the model, including annual escalation rates, projections based upon econometric modeling, and institutionally derived prices.

Alternative energy costs are as important as solar add-on costs. One must have reasonable estimates of the cost of options facing the consumer. It is relatively simple, although the time and dollar resources required are far greater than one might suspect, to acquire present energy costs for the continental U. S. It is, however, extremely difficult to project what these prices might be 5, 10 or even 15 years from now. Yet, these future energy prices play a large if not dominant role in any economic evaluation or decision process for solar space heating options are generally high first-cost items. Therefore, a number of alternative futures has been and must continue to be examined in the overall economic performance evaluation of solar designs. Table 2 contains a representative set of energy costs (specified in $\$/10^6$ Btu and adjusted for heat delivery efficiency) that has been recently used in an assessment of passive thermal mass storage walls.

Financial parameters must be specified as the final input component. These include terms of the hypothetical loan, inflation and discount rates, taxes and tax brackets, insurance requirements, salvage or resale value, system life, period of financial analysis, and solar incentive options.

METHODOLOGY

Each of the inputs enters into the methodological portion of the LASL/UNM code, which combines all of the information into a constrained or unconstrained optimal sizing algorithm based upon alternative formulations of life cycle cost analysis (Noll, 1979b). Average, marginal, and delivered heat cost curves are generated which express the solar economics in equivalent annual $\$/10^6$ Btu terms. At the optimum (equivalent annual marginal cost of the last passive solar sizing increment just equal to the equivalent annual cost of the conventional energy alternative) net present values (NPV) over the life cycle are at a maximum. However, this only insures solar feasibility (by our definition) if the NPV is positive. Since life cycle cost analysis has been criticized as being an incomplete description of the consumer behavior process, we calculate other economic indicators including years to positive savings (YTPS), simple (SPBK), and discounted payback (DPBK), return on investment (ROI), and equivalent annual costs (EAC). The analysis proceeds in this manner so that calculations are made for each location, each year, and according to each of the major fuel types (natural gas, heating oil, and electricity). Maximum sizing constraints, budget limitations, and payback requirements can be specified to put bounds on the optimal sizing algorithm, in which case we have a constrained optimization procedure.

More precise information for each of the 200 plus sites in the macro approach (component) of the LASL/UNM code is presently being collected. This includes property tax rates, marginal income tax brackets for home buyers, appraisal and resale portions (solar additions), and local home building costs. This is in addition to the update solar add-on costs and alternative energy prices mentioned above. This information is necessary to ensure the alternative economic and financial criteria employed in the actual economic performance evaluation operate as presently structured.

The actual computer code with its associated data bases is continuously being modified to reflect the new information and improvements being made to the economic optimization alogrithms. In addition, the code is being rewritten so that in the near future it can be made available to other individuals and institutions involved in solar residential assessments.

In the micro approach (component) of the LASL/UNM economic performance to design parameters such as storage volume and building load to glazing area ratios) are used to generate sizing isoquants (combinations of inputs yielding identical solar fractions) from which an expansion path (locus of least cost designs) can be determined. Optimal sizing is conducted along the expansion path, or bounds can be added as before to constrain the feasible solution or design space.

A recent addition to the micro approach has been the inclusion of ownership periods. With the average home owner changing residences every 5-9 years, it becomes fairly important to examine differences in the decision process (purchase of solar options) when expected periods of concern are less than those used in traditional life cycle cost analysis. This shortens the period of solar assessment and consequently reduces information needs. However, because solar is a capital intensive investment, the shorter time period may also reduce potential benefits (foregone fuel costs) to the point where solar is no longer competitive. By proper inclusion of inflation rates, income tax reductions from interest payments, and most importantly the resale potential of solar additions, the shorter time period of analysis should prove to have only minor impact upon the ultimate consumer decision.

OUTPUT

The output portion of the LASL/UNM model records the first (and subsequent) calculated year of life cycle feasibility for each location against each fuel type (natural gas, heating oil, and electricity). System size (ft^2), cost ($), and yield ($10^6$ Btu/year) at the optimum are generated along with the NPV, YTPS, SPBK, DPBK, ROI, and EAC. Much supporting output data can also be generated, including the performance and cost curves (tabulated data), current and equivalent annual energy prices, value of proposed tax credits and low interest loan subsidies, and cash flow analysis by year. This information is usually in the form of computer printout. Subsequent transformation of that information gives rise to the maps, figures, and tables that highlight major results and conclusions. Some of the graphics has also been computerized, while the remaining transformations are usually completed by hand.

Because of the inherent difficulty of projecting market penetration rates (Schiffel, Costello, and Posner, 1978) the LASL/UNM model does not presently include a formalized market penetration component. However, current efforts are being devoted to identification, refinement, and incorporation of available market penetration models into the LASL/UNM code. Much of the penetration work has concentrated upon consumer demand characteristics with the implicit assumption of a demand-pull supply response. In a highly dissaggregated residential building market, this approach may not be entirely appropriate. Characterization of supply sector trends and behavior must be incorporated into such market penetration models, and is therefore the thrust of some current research efforts.

Once an acceptable penetration methodology is incorporated into the LASL/UNM model, output will include passive (and active) penetration into the new and retrofit housing markets, projected energy savings and fossil fuel displacement, dollar value of investment and government incentive expenditures, and other macroeconomic indicators.

SOLAR ASSESSMENTS

From the types of outputs defined above (based upon a well-specified set of input parameters, and the economic/financial parameter values involved--assumed--for the evaluation process), solar assessments are made that include sensitivity studies, evaluation of incentive schemes, and interpretation of output data. Figure 3 and Table I illustrate the results of a particular computer run of a passive thermal mass storage wall (Trombe type) with R-9 night insulation. All parameters were held constant in this comparison with electric resistance conventional heating, except the variable cost of the double-glazed Trombe wall which we set at $12, $18, and $[illegible] per ft^2 of glazing.

In all of the chosen locations (except Seattle, WA) the Trombe wall competes favorably against the electric resistance alternative at the $12/ft^2 variable cost, whereas 18 locations (19 total including Seattle, WA) dropout against the benchmark cost of $18/ft^2 (Figure 3). At $24/ft^2, additional states drop from the feasible set leaving only 12 portraying solar competitiveness (keyed by horizontal markings in Figure 3). Optimal system size declines along with NPV when solar costs increase as shown for select locations in Table 3. Years to positive savings is zero in all cases, with simple paybacks ranging from 11 to 16 years. Many other parametric variations can be made to test partial and total sensitivities of economic feasibility to variations in performance, cost, energy future, and financial assumptions. The final results indicate where particular passive configurations compete best and why.

The above discussion highlights only one aspect of our on-going solar assessment work. Comparative evaluations between and among alternative solar configurations are presently being carried out for those systems/designs with nationwide performance computations available. This leads to revealing contrasts on solar system sizing, costs, and various financial indicators portraying the economic competitivess of each configuration. Integrated solar designs, those designs comprising more than a single concept (e.g., Trombe wall <u>and</u> direct gain), are to be evaluated next.

A graphical representation of the microeconomic approach is illustrated by the isoquants, expansion path, and constraints shown in Figure 4. In the Trombe wall example, passive solar isoquants are generated which show combinations of glazing area and wall thickness that provide equal percent solar contribution on an annual basis. A total add-on cost is associated with each sizing combination along the isoquants, so a locus of least cost points is determined which we call an expansion path. With no constraints, optimal sizing occurs along the expansion path to maximize NPV. However, the feasible solution space can be constrained by imposing minimum thickness (building codes), maximum glazing area (physical limitations), and maximum budget constraints. The budget constraint shows all combinations of area and thickness that can be installed for an equivalent outlay, for example $4000, or any other predetermined amount. In the particular depiction of Figure 4, only the budget limitation constraints the expansion path. With a larger budget allowance, the area constraint then would become binding. If for comfort reasons the designer wanted a thicker Trombe wall, sizing could proceed along the comfort thickness constraint (18 inches in Figure 4) until the budget or area constraints were met. This microeconomic approach allows quantification of constraints that normally enter the design process but usually are not given explicit recognition.

The microeconomic component of the LASL/UNM economic performance code is being expanded through development of simplified design tools. These tools include (1)a step-by-step approach to economic evaluation of solar for a specific residence in various locales (DOE, 1979), (2) a set of consistent and correct mathematical expressions for the economic evaluation of solar feasibility/desirability, (3)a set of simplified formulas with regional coefficient values for the computation of isoquant and expansion path curves, and (4)a set of "cook book" procedures and accompaning table values (factor computations) for use in assessing solar potential.

FUTURE PLANS

In addition to completing solar assessments, for a number of newer designs, much of the upcoming work for the remainder of this calendar year has been identified in discussion above. Briefly, the LASL/UNM economic performance model (code) is being expanded to encompass over 200 locations (macro) and additional solar configurations. Alternative sizing criteria are being explored, builder and buyer interactions are being characterized, and the integration of housing and market penetration components for passive and active solar is being pursued. Work is continuing on the microeconomic analysis of passive designs in select citi s to determine the optimal combination of sizing and design option parameters in various climates. The LASL/UNM computer code and standard data bases are being modified and documented so as to make them available to others actively involved in solar assessment activities.

SUMMARY

This paper has presented a brief overview of our approach to the economic evaluation of residential solar heating systems. As should be fairly apparent from the substantive discussion, economics serves as the central focus or structure under which the overall solar assessment is being carried out. However, and this is an extremely important point, information from and proper consideration of other disciplines are critical (and even mandatory) aspects of all analyses. That is why so much weight has been and is continuing to be placed on the solar design process, the determination of solar performance under alternative design and climatic conditions, the proper computation of solar add-on costs, and a reasonable and realistic evaluation of future conventional heating costs.

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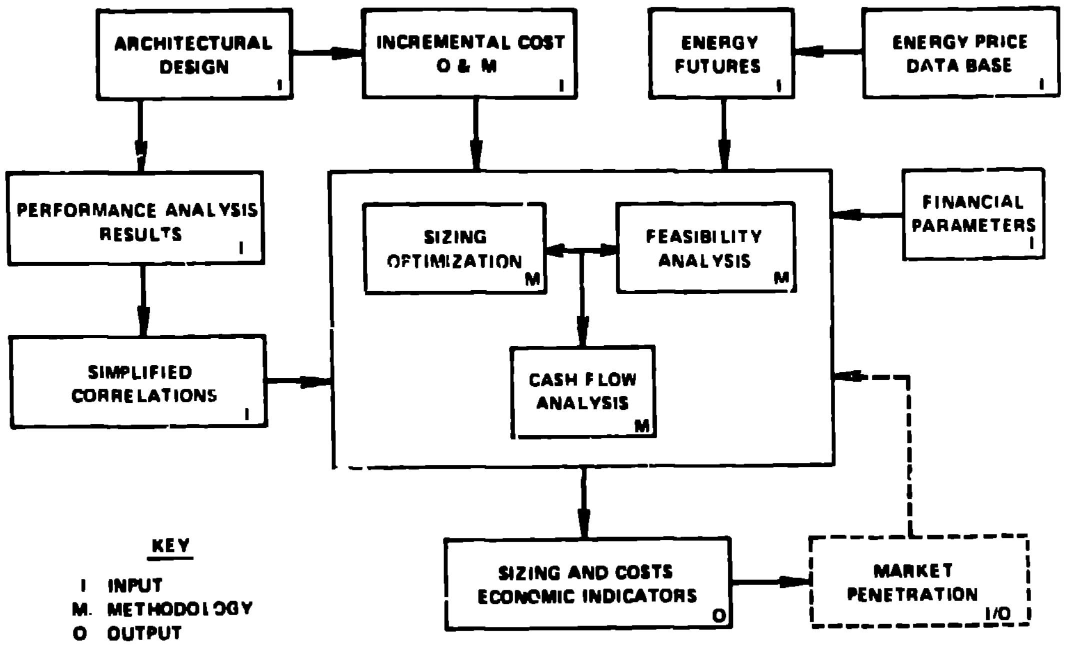

Figure 1. Schematic of LASL [illegible] Economic Performance Model

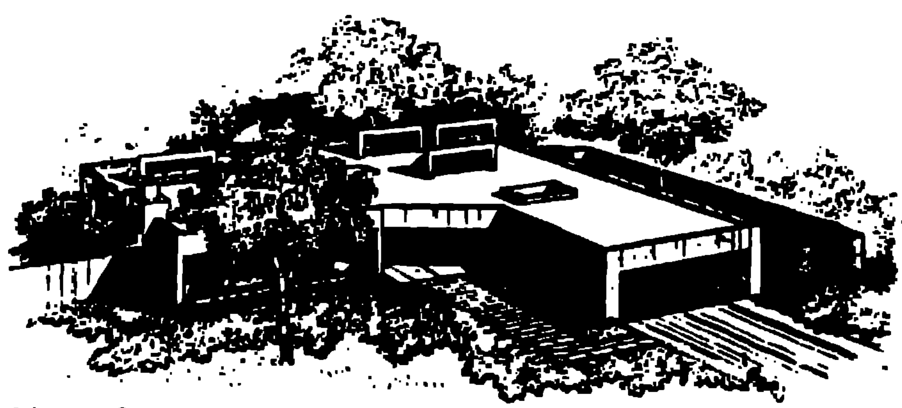

Figure 2. Architectural Rendering of Direct Gain Tract Home Concept

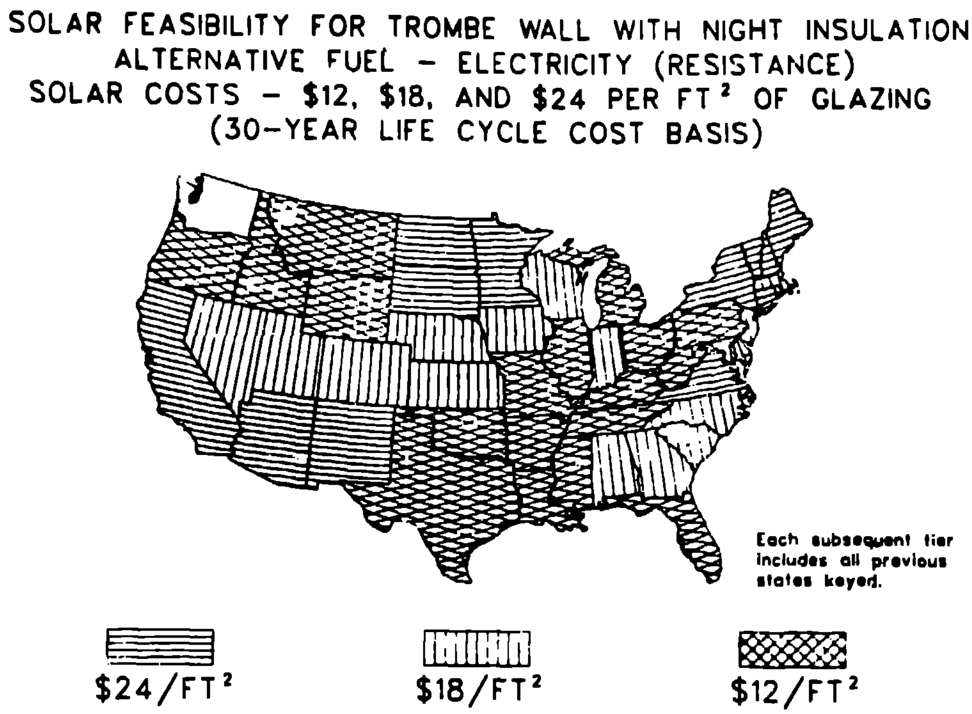

Figure 3. Map of Solar Feasibility for Trombe Wall concept (macro approach)

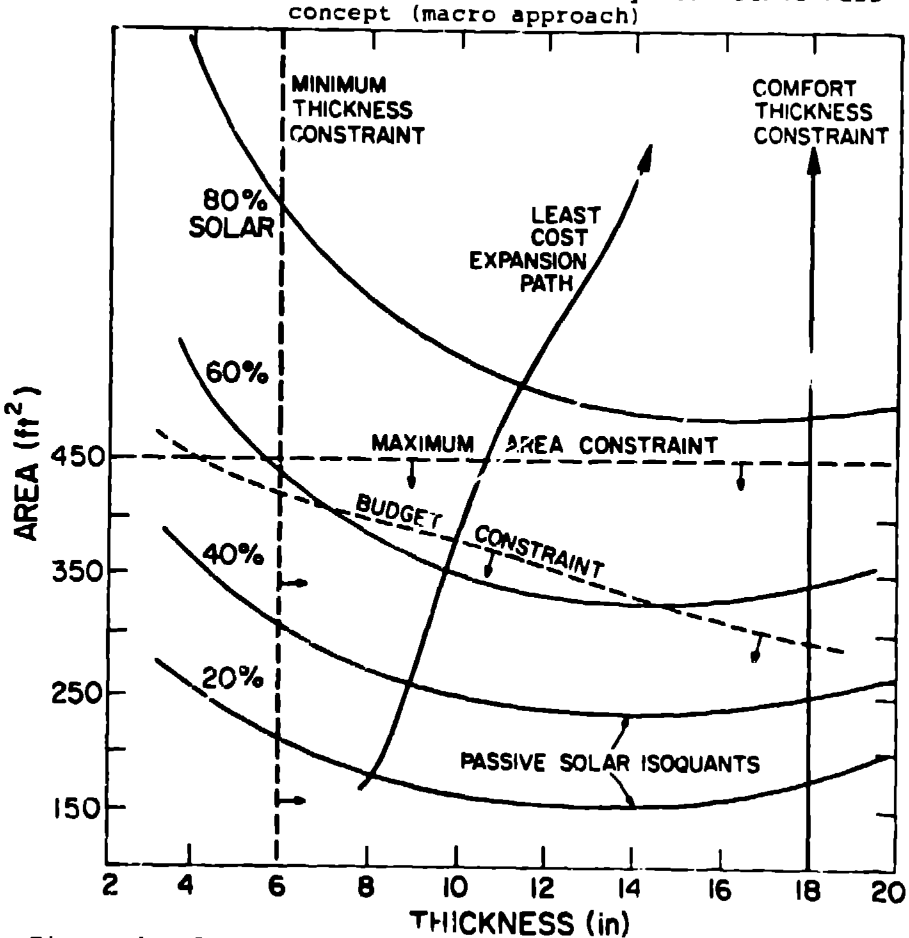

Figure 4. Isoquants, Constraints, and Expansion Path for Trombe Wall, Albuquerque, NM (micro approach).

TABLE 1

DETAILED COST* BREAKDOWN FOR DIRECT GAIN
($/ft^2 of Glazing)

South Facing Window	Cost**	Clerestory Window	Cost**
Glazing--Glass (Tempered) double 2 @3/16"	3.54	Glazing--Glass (non-tempered) double 2 @3/16"	2.35
Framing-- 4' x 8' = 24ft$_L$	2.86	Framing-- 4' x 10' = 28ft$_L$	2.70
Header Trim or Overhand	1.36	Roof Structure	4.95
Concrete Slab-- 2" additional	1.74	Concrete Block 8"	8.15
Concrete Block-- 8"	3.37	Footing-- 8" foundation	1.45
Interior Wall Credit	(1.10)	No Wall Credit	--
Exterior Wall Credit	(2.27)		
Total System	9.50	Total System	19.60
Night Insulation (R-9)	4.50	Night Insulation (R-9)	5.40

*Dollar Costs are for National averages.
**Includes both materials and labor.

TABLE 2

COST OF DELIVERED FUEL* ($/10^6 BTU) BY FUEL TYPE -CURRENT & ANNUALIZED FOR 1978 AND 1990 DOLLARS**
(Six Selected Sites)

Location	Natural Gas Current 78	Natural Gas Current 90	Natural Gas Annualized 78	Natural Gas Annualized 90	Heating Oil Current 78	Heating Oil Current 90	Heating Oil Annualized 78	Heating Oil Annualized 90	Electric Resistance Current 78	Electric Resistance Current 90	Electric Resistance Annualized 78	Electric Resistance Annualized 90	Heat Pump Current 78	Heat Pump Current 90	Heat Pump Annualized 78	Heat Pump Annualized 90
Albuquerque, NM	2.64	10.46	8.05	20.00	6.21	13.79	12.23	25.34	12.15	27.55	[illegible]	[illegible]	6.74	13.5[illegible]	[illegible]	24.52
Madison, WI	3.73	12.58	10.01	24.01	6.05	13.47	11.94	[illegible]	12.20	27.66	24.9[illegible]	[illegible]	8.81	17.72	[illegible]	[illegible]
Boston, MA	5.06	15.26	12.43	28.00	6.44	14.25	12.64	26.17	15.97	36.20	32.69	74.12	9.67	19.46	17.50	35.21
Seattle, WA	4.25	13.63	10.96	25.91	6.36	14.09	12.50	25.88	5.24	11.88	10.73	24.32	2.92	5.67	5.28	10.63
Charleston, SC	2.96	11.04	8.63	21.74	6.24	13.85	12.78	25.44	13.72	31.11	[illegible]	[illegible]	6.66	13.28	11.94	24.02
Omaha, NB	2.59	10.29	7.96	19.89	6.10	13.57	12.03	24.94	12.08	27.38	24.73	56.07	7.87	15.84	14.24	28.66

*Corrected for combustion effeciency as follows

Gas = .75
Oil = .60
Electric Resistance = 1.00
Heat Pump = variable COP by location

**The Annualized cost in year t is defined as $A_t = CR \cdot \sum_{t=1}^{T} \left(\frac{1}{1+i}\right)^t C_{(t+t)}$

where

C_t = current delivered cost ($/10^{6}Btu) in year t
i = nominal discount rate = r + AIR
T = system life in years
CR = capital recovery factor = $\frac{i}{1-\left(\frac{1}{1+i}\right)^T}$
e = 1.13 (1978-1990)

A_t = annualized delivered cost ($/10^6 Btu) in year t
r = real discount rate
AIR = annual inflation rate

Values used in the derivation of these figures are as follows

r = .015 T = 30
AIR = .06 CR = .102 (This assumes mortgage & nominal discount rates are identical.)
i = .095

TABLE 3

SELECTED FINANCIAL INDICATORS FOR A PASSIVE TROMBE WALL DESIGN*

Location	Year of Feasibility	Solar Fraction	Solar Cost (1978 Dollars)	Average Cost of Solar ($10^{6}Btu)	Net Percent Value (1978 Dollars)	Simple Payback Period Years)	Years to Positive Savings
			$12/ft^2 of Glazing**				
Albuquerque, NM	1978	.55	2902	8.68	1785	11	0
Boston, MA	1978	.40	3887	12.34	1902	12	0
Charleston, SC	1978	.50	1446	10.17	801	12	0
Madison, WI	1978	.35	3565	9.26	1839	12	0
Omaha, NB	1978	.35	2994	9.27	1498	12	0
Seattle, WA			-No Feasibility-				
			$18/ft^2 of Glazing**				
Albuquerque, NM	1978	.25	1653	10.81	470	14	0
Boston, MA	1978	.10	1151	14.62	286	14	0
Charleston, SC	1978	.15	525	12.32	328	14	0
Madison, WI	1978	.10	1206	10.97	328	14	0
Omaha, NB	1978	.10	1091	11.80	184	15	0
Seattle, WA			-No Feasibility_				
			$24/ft^2 of Glazing**				
Albuquerque, NM	1989	.10	823	13.54	115	16	0
Boston, MA			-No Feasibility-				
Charleston, SC			-No Feasibility-				
Madison, WI			-No Feasibility-				
Omaha, NB			-No Feasibility-				
Seatt'e, WA			-No Feasibility-				

*All dollar values are in real terms.
**Nationally indexed cost which is adjusted for regional variations in materials and labor costs.